

RESULTS OF SOME EMPIRIC RESEARCHES AS TO THE GENERAL MOVEMENTS OF THE ATMOSPHERE.

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INTRODUCTION.

A Kepler would not have been possible if a Tycho Brahe had not preceded him. The same thing is true in meteorology. Before it may be possible to study seriously the causes of the general movements of the atmosphere it is necessary first and independently of all preconceived theory to seek to determine with precision what actually takes place in the atmosphere, that is to determine by direct observations what these movements are and what is their nature. From the beginning of dynamic meteorology in the middle of the past century the principal aim of our generation has been to concentrate all our efforts on one objective: the assembling of material sufficiently good and of suitable range, the exercising of our patience in elaborating these elements in the most diverse directions for the purpose of facilitating comprehensive views and the showing of characteristic features.

We shall endeavor to present here the principal results relative to the general movements of the atmosphere attained by empirical researches.

All the representations of the general movements of the atmosphere hitherto published are the results of theoretical considerations more or less ill founded. For a long while we have known rather well the mean direction of the wind at a large number of stations in almost all of the countries of the world and also, thanks to the co-operation of all of the mariners and to the classic works of Maury, of Brault, of Köppen, and of other scholars, our knowledge of the régime of the winds over the seas has been for a long while very much detailed. But the movements of the upper layers of the atmosphere were almost unknown until recently. We knew of the countertrades which had been encountered on the summits of the islands, like Teneriffe in the Atlantic and Mauna Loa in the Pacific. This phenomenon was considered a proof of the law announced by Halley in 1686: The temperature of the air, which depends on the calorific influence of the sun, decreases from the Equator to the poles, now there must exist constantly an upper wind, or equatorial current, blowing from the Equator to the poles, and a lower wind, or polar current, blowing from the poles to the Equator.

In addition there was considered the principle stated by Hadley in 1735: Whatever may be the direction taken by an atmospheric current the terrestrial rotation deviates this current to the right in the Northern Hemisphere, to the left in the Southern.

This principle of Hadley's has been proven by mathematical theory and has been verified by the well known experiments of Foucault and others.

The principle of Halley's has also been admitted by the greater number of meteorologists. Dove did not adopt it. He thought that the countertrade descended at the tropics to the surface of the earth, and the winds from southwest or west prevailing over the seas of the north temperate zone and the corresponding winds from the northwest or west in the Southern Hemisphere were considered by him as extensions of the descended countertrades, the equatorial currents as advancing toward the poles while the polar currents move in opposite direction, from polar regions to tropical ones.

These ideas of Dove's are abandoned, but lately better founded doubts as to Halley's principle have arisen. The important discovery by Teisserenc de Bort that the atmosphere consists of two strata: The troposphere extending from the surface of the earth to the height of 8-10,000 meters and the stratosphere lying above makes a vertical circulation so simple but little probable. In reality all of the troposphere consists of cyclonic and anticyclonic circulations with their ascending and descending currents, and consequently two superposed currents moving in opposite directions can not exist there. In the stratosphere vertical currents do not exist, and the horizontal currents have not been studied. It is true that above the equatorial zone the troposphere rises to very great heights, so that there the stratosphere is found only at heights much greater than in Europe; and also that over the Atlantic north of the equator and, by M. Berson, over Lake Victoria Nyanza cirriform clouds have been observed moving from the southwest at great heights. But even if there were in the stratosphere a general movement from the southwest toward the pole, which would lead to a descending current in the neighborhood of the pole, that would hardly indicate a vertical circulation of the entire atmosphere between the equator and the poles. It must be noted that at the lower limit of the stratosphere over Europe the pressure of the air is slight—200 mm. at the height of 9,600 meters—and at the height at which the stratosphere is found over the equatorial zone the pressure of the air diminishes to 50 mm. (at 17,400 meters), and it is at this height that this supposed equatorial current would begin in the stratosphere. But at this place the mass of the air set in motion is very small in comparison with the total mass of the atmosphere. Now then, a general circulation of the atmosphere according to Halley's principle can not be spoken of.

Recently another very serious objection to this principle has been raised by Sir Napier Shaw and others. They point out that the thickness of the atmosphere is infinitely small relative to the size of the earth. In fact it is relatively of the same thickness as the paper which covers terrestrial globe of ordinary size. A regular, double circulation in a layer so thin seems impossible. It is a wonder if it exists between the Equator and the Tropics.

I.

THE GREAT CURRENTS OF THE ATMOSPHERE INDICATED BY THE MOVEMENT OF CYCLONES AND ANTICYCLONES.

The most regular and dangerous cyclones are the whirling tropical storms moving in a trajectory. Redfield, Reid, Piddington, and other scholars and also the navigators since Dampier, have all observed that the force of the wind is very different on the two sides of the disk whirling in its march. The right side is called the dangerous semicircle and the left side the more easily navigated semicircle. This has been explained by assuming that the cyclone is a whirl carried by a great current of air. In that case it is evident that in the northern hemisphere the motion of the rotation and that of the translation are in the same direction in the right semicircle and opposed in the left semicircle.

In both hemispheres the cyclones move from east to west within the Tropics, deviate to the right in the Northern Hemisphere and to the left in the Southern according to Hadley's principle, and on entering into the temperate zone they move consequently successively toward north, north-northeast, northeast, and east to the north of the equator and toward south, south-southeast, southeast, and east to the south of it. The trajectory is nearly parabolic with the vertex at latitude 20° – 30° , according to the season, in the Northern Hemisphere and at latitude 15° – 20° over the Pacific Ocean. In the temperate zones the cyclones, or barometric minima, are less regular and their march more variable, but generally toward a point between northeast and southeast. Clement Ley (1876) was the first to study in more complete detail the march of these minima. (1) He found that generally the center moves nearly at right angles to the direction in which the isobars are most compact. If the steepest gradient is found to the east, southeast, or south of the center then the depression moves most frequently toward north, northeast, or east, etc. However, if the steepest gradients are found to northwest, north, or northeast of the center, it most frequently remains motionless or moves (ordinarily slowly) in any direction; although a movement toward the west, which should then be found, is in reality very rare.

This fact inspired in Clement Ley this idea, "more simple than correct perhaps," says he, that the direction of the center is the resultant of two independent forces; one, the force of the gradient, which directs the center at right angle to the direction in which the isobars are most compact; another, "a force unknown and a little stronger" than the first, which carries it toward northeast or east.

In studying more in detail the northern portions of the minima (2) I have ascertained that the depressions having low pressure to the north are not closed (above) north of the center. But if on the other hand the depression passes to the south of a maximum, the whirl has a more considerable height and is closed even at the north of the center.

This is easily explained by assuming that the depressions are whirls in a current of air moving from west to east. In that case it is necessary that they have with the tropical cyclones a dangerous semicircle on the right and a safer semicircle on the left.

If the current from west to east—"the unknown force" of Clement Ley—is a little stronger than the velocity of rotation north of the center, the movement of the air relative to the surface of the earth will be from west to east. But the velocity of rotation depends on barometric gradient, and that must generally be greater if there is a maximum toward the north, and in that case the chance is greater that the velocity of rotation will exceed that of the current from west to east, but then the whirl is closed to the north of the center. The paths of the minima are more irregular in the Northern Hemisphere because of the irregular distribution of land and sea surfaces, on the other hand in the southern hemisphere "the brave west winds" of the sailors caused by winds from the west at the south of tropical maxima and those at the north of the minima of the temperate zone have extraordinary constancy.

The director of the observatory at Sydney, H. C. Russell, was the first to study the march of anticyclones over the Indian Ocean (3) and Australia. He found that the permanent anticyclones indicated on the charts showing mean isobars of the Tropics are caused by a series of anticyclones which pass continually from west

to east at almost the same latitudes (the Tropic of Capricorn), in the same way that the low pressure south of Iceland in winter is due to a continuous series of depressions which traverse this part of the North Atlantic Ocean.

The paths are found at 37° – 38° south latitude in summer, at 29° – 32° latitude in winter.

These studies have been continued by William Lockyer in his interesting treatise on the circulation of the winds of the Southern Hemisphere (4). In comparing the barometric curves at two stations situated at almost the same latitude, but at a distance of several degrees of longitude, he was able to determine the time in which the maximum had passed from one station to the other.

From a great number of such measurements he found that the mean velocity per day is:

	Longitude.
Over southern Africa.....	12°
Over Australia.....	11.5°
Over South America.....	11.1°
Over the continents.....	11.5°

Over the oceans the velocity per day is 9.2° of longitude for all oceans south of the Equator.

An analogous research relative to the minima of barometric waves in the antarctic regions has given for the mean velocity of cyclones nearly the same value, 9° – 10° of longitude per day.

Now in the Southern Hemisphere there are two whirl zones, anticyclonic around the Tropic and cyclonic south of latitude 60° . This is in perfect agreement with the charts of mean winds for the Southern Hemisphere. In fact, all around the earth between 40° and 55° south latitude there prevail the "brave west winds," the most constant winds that exist. They result from constant gradients between the maxima at the north and the antarctic minima. The régime of the winds is much more simple over the Southern Hemisphere, almost entirely covered by the oceans, than over the Northern Hemisphere, where the continents cause great perturbations.

Figure 1 (on plate facing p. 391) shows the circulation in the Southern Hemisphere according to William Lockyer.

Hence the study of the paths of cyclones and of barometric minima has proven that there is a constant current from east to west within the Tropics and currents in the contrary direction, from west to east, over the temperate zones.

II.

THE GREAT CURRENTS OF THE AIR AS INDICATED BY THE MEAN DIRECTIONS OF THE CLOUDS.

In order to study the mean directions of the currents of the air at different altitudes above the ground the observations of the movements of the different forms of clouds have been examined. Observations were begun by myself in Sweden in 1873 and somewhat later by Clement Ley in England. Gradually such observations were begun in several countries. But at the beginning the observations were too infrequent, oftentimes their value was questionable and—what was worse—the classification of clouds was different in different countries. Besides it could not be affirmed *a priori* that the mean direction of a certain form of cloud observed was that of the prevailing wind at the same height. In fact in order that the direction of the upper currents might be determined it was first necessary that the clouds should float there, since without this the currents are invisible; then it was necessary that these clouds be not hidden by lower

clouds. Now it is evident that these conditions are not always satisfied.

Despite these hindrances we treated this question in a preliminary manner.

In 1885 (5) we discussed as regards Europe the observations of the movements of the upper clouds made at a large number of stations, and in 1889 (6) we extended these researches as far as possible over all the surface of the earth. From these well harmonizing results I drew the following conclusions:

1. In the upper regions above the temperate zones there prevail currents whose direction is in the mean from west to east:

2. Within the Tropics their direction is the opposite, or from east to west;

3. The direction of the upper currents seems to coincide almost with the mean path of the centers of barometric depressions.

In February, 1887, R. Abercromby and myself presented two papers before the Royal Meteorological Society in London, in which we proposed a new classification of clouds. The Meteorological Conference at Munich in 1891 recommended this classification as international, and named a commission on clouds, of which I had the honor to be president, to take the measures necessary for the publication of an International Cloud Atlas, in colors and of moderate size and cost (7).

At the same time the Conference proposed that measurements of the movements and of the heights of clouds be undertaken for a year at different stations, distributed over the entire earth, and I was asked to prepare the instructions for these observations.

All this preparation having been made, the permanent meteorological committee and the commission on clouds met at Upsala in August, 1894. There had been prepared for this meeting a display containing more than 300 reproductions of clouds—in photographs and in colors—from different parts of the earth. After having chosen the forms to be reproduced in the International Atlas, the commission charged another commission with the publication.

This was composed of H. Hildebrandsson, A. Riggenbach, and Léon Tiesserenc de Bort. In addition the commission determined the description and the definitions of the different forms of clouds, as well as the instructions for the observers. All of the proposals were accepted by the permanent committee, which invited all the meteorological institutions of the world to prosecute observations and measurements of clouds from May 1, 1896, to May 1, 1897, according to the instructions adopted.

As in several countries many stations had not been able to begin the observations on the date fixed at Upsala, the Conference assembled at Paris in 1896 resolved that it would be desirable that the direct observations of clouds be continued at such stations until the close of 1897.

A large number of countries took part in this great enterprise, and the results were published everywhere in the form proposed by the commission on clouds.

I published the principal results of this mass of observations in a report to the International Meteorological Committee. The most interesting part of this report is that on the general circulation of the atmosphere (8).

These researches terminated in the following results.

1. Upper clouds.

The results found in the papers of 1885 and 1889 are fully verified: In the region of the upper clouds, cirrus and cirro-stratus, the direction of the winds is in the mean from west to east in the temperate zones and from east to west in the tropical zone.

Figure 2 and [omitted] Tables 1 and 2 give the results for some selected stations.

Thus at Blue Hill, near Boston, in America; at Upsala, in Sweden; at Irkutsk, in Siberia; and at Hakodate, in Japan; the wind at the height of the upper clouds has everywhere a direction from west to east with a north or south component according to the season.

On the other hand the upper wind is from the east at the tropical stations: Square 3 lying between the Equator and 10° north latitude and between 20° and 30° west longitude and near Africa, Paramaribo in Dutch Guiana, and San José in Central America.

At Mukimbungo, Congo State, the mean direction of the cirrus clouds is from E. 37° S.

We give in addition for the temperate zone the following data on the mean movement of upper clouds:

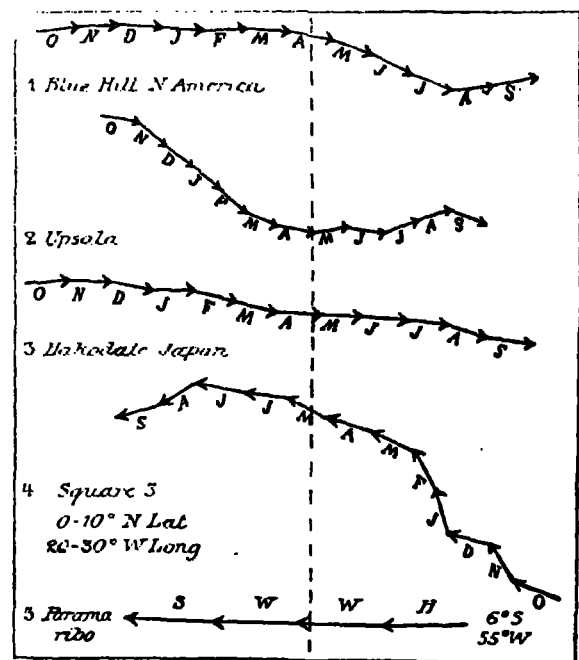


FIG. 2.

TABLE 3.

	Means of all stations		Nora, Sweden, 59° 32' N.	Tomsk, Siberia, 50° 30' N.
	England.	Germany.		
January.....	W. 2° N.	W. 7° S.	W. 49° N.	W. 42° N.
February.....	W. 10° N.	W. 42° N.	W. 32° N.	W. 50° S.
March.....	W. 21° N.	W. 11° N.	W. 30° N.	W. 34° S.
April.....	W. 9° N.	W. 15° N.	W. 12° N.	W. 13° N.
May.....	W. 5° S.	W. 36° S.	W. 2° N.	W. 73° N.
June.....	W. 3° N.	W. 8° S.	W. 4° S.	W. 37° S.
July.....	W. 11° N.	W. 12° S.	W. 8° S.	W. 20° S.
August.....	W. 5° N.	W. 13° S.	W. 1° S.	W. 22° S.
September.....	W. 1° N.	W. 6° N.	W. 9° N.	W. 4° S.
October.....	W. 9° N.	W. 35° S.	W. 14° N.	W. 2° S.
November.....	W. 15° N.	W. 5° S.	W. 33° N.	E. 70° S.
December.....	W. 58° N.	W. 2° N.	W. 29° N.	W. 10° S.

2. The trade wind zone.

In the Atlantic there is no station situated in the middle of the trade-wind belt, but in the southeast trade wind of the Indian Ocean there is the excellent observatory of Mauritius. In the official report of the director, T. F. Claxton, for 1897 we find the mean monthly directions of the upper clouds and those of the winds for the years 1877-1897. The total number of cloud observations is 3,393.

Table 4 [omitted] and figure 3, B, give results.

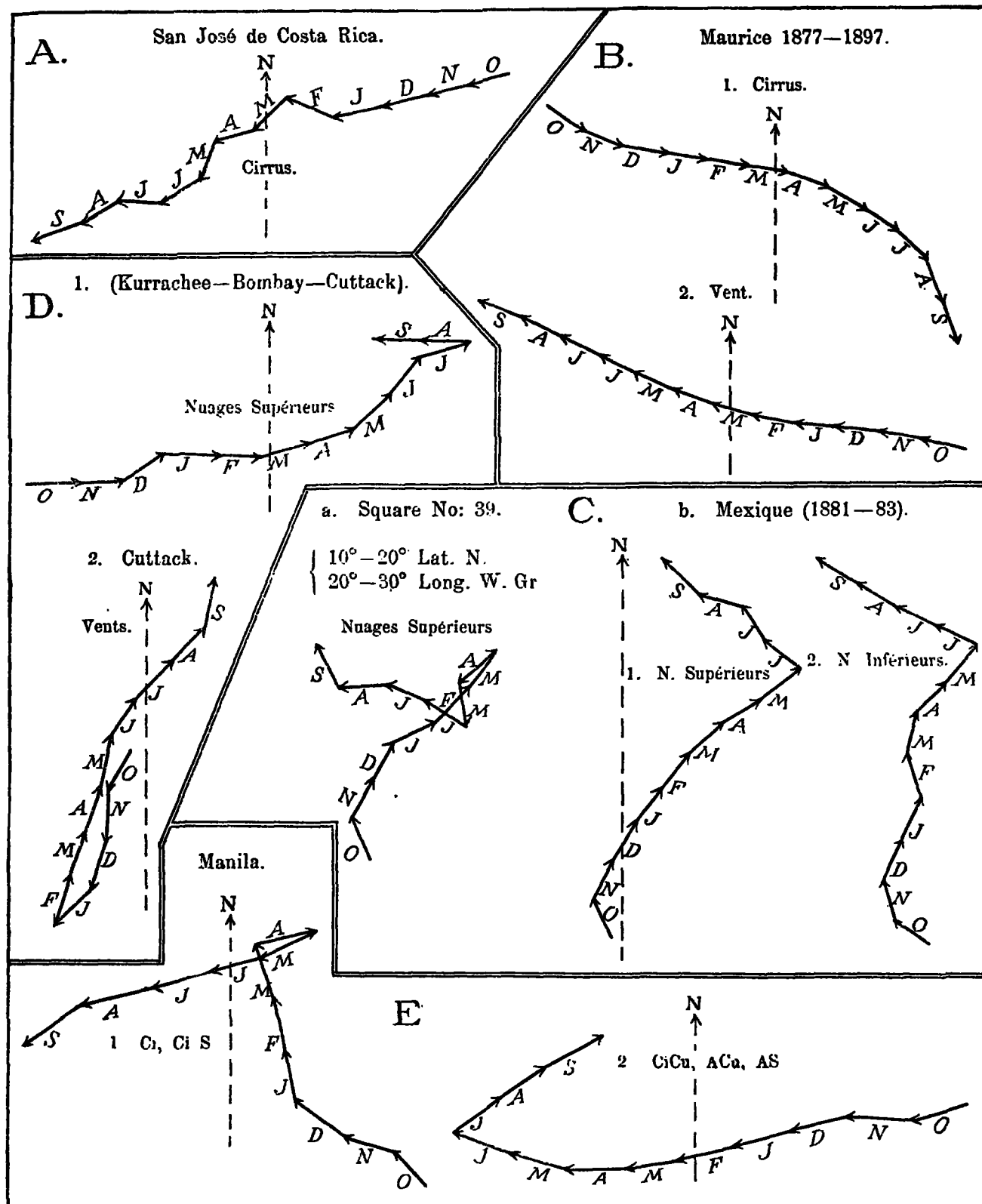


FIG. 2.

Thus in the midst of the southeast trade wind the counter-trade blows nearly from northwest. North of the Equator it should blow from the southwest.

In the theories of Ferrel and J. Thomsen it is stated that the counter-trade continues, at least in large part, as an upper southwest wind as far as the vicinity of the north pole. We shall see that this is not true.

In reality the counter-trade of the northern hemisphere, like all of the winds, deviates to the right and at the polar limits of the trade wind zone has become a west wind. This deviation increases, as is known, with elevation, for an upper wind deviates to the right of a lower current. Above a south wind, for example, the lower clouds move from south-southwest, the intermediate (middle) clouds

from southwest, the upper clouds from about west, as has been well proven for a long while.

On Teneriffe the trade wind blows over the sea, at the summit of the peak there blows a southwest wind. Cirrus clouds are rare, but 76 observations in winter are thus distributed:

N.	NNW.	NW.	WNW.	W.	WSW.	SW.	SSW.
1	1	0	0	27	6	7	2
S.	SSE.	SE.	ESE.	E.	ENE.	NE.	NNE.
5	3	5	3	2	0	2	1

Thus at the elevation of the cirrus clouds the direction of the upper winds is W. 15° S. in winter over Teneriffe.

At San Fernando (36° 37' N. lat.) at the northern limit of the trade wind we have (1876-1885):

TABLE 5.—San Fernando.

Month.	Cirrus.	Month.	Cirrus.
January.....	E. 30° N.	July.....	W. 4° S.
February.....	W. 24° N.	August.....	W. 3° S.
March.....	W. 8° S.	September.....	W. 4° N.
April.....	W. 7° N.	October.....	W. 3° N.
May.....	W. 3° S.	November.....	W. 20° N.
June.....	W. 3° N.	December.....	W. 35° N.

We have no observations from the Cape Verde Islands on clouds, but we shall see later that observations with sounding balloons have proven that there the upper wind is about southeast.

Thus the upper tropical wind from the east deviates to the right and comes from the southeast at the Cape Verde Islands, from southwest at the middle of the trade wind belt, and from west at its northern limit. It is the same curve that is followed by the tropical cyclones. Hence a vertical circulation between the Equator and the poles does not exist.

3. Upper monsoons.

The thermal equator, the trade winds, and the high pressure areas at the Tropics have, as is well known, an annual oscillation, continually shifting with the sun from north to south and vice versa. Thus a large belt north of the thermal equator lies under the counter-trade from the southwest in winter and under the tropical current from the east in summer. As proof we give the following observations.

In Tables 6 and 7 [omitted] and on figure 3 C we give the results of observations on cirrus clouds in Square No. 39 (10°-20° N. lat. and 20°-30° W. long.), and the means of observations of upper and lower clouds made from 1875 to 1884 at several stations in Mexico between 23° and 19° north latitude.

4. Asiatic monsoons.

The Rev. Marc Dechevrens, director of the observatory at Zi-Ka-Wei, near Shanghai, was the first to find that the mean direction of the cirrus clouds has no relation to the mean distribution of air pressure at the surface of the earth. Despite the high pressure in winter and the low pressure in summer over eastern Asia the upper currents there come in every season constantly from the west. (Tables 8, 9, and 10 omitted.)

We have proven that it happens everywhere in these parts that the monsoons do not always reach the height of the middle clouds. Let us take as examples Manila (14° 36' N. lat.) under the system of tropical winds from the east, the means of the stations Kurrachee, Deesa, Bombay, Poona, Belgaum, Nipur, Jubbelpore, and Cuttack in central India (mean latitude 20° N.) and Zi-Ka-Wei (31° 11.5' N. lat.). (Tables 8-10 omitted: see fig. 4.)

Hence the monsoons do not belong to the general movement of the atmosphere; it is necessary to consider them as great disturbances, whose height hardly exceeds 4,000 to 5,000 meters. Above them the great currents move as usual from the west or from the east.

5. The North Temperate Zone.

With the exception of the monsoon regions the mean direction of the wind in the Temperate Zone is west from the ground up to the height of the upper clouds.

Here are some examples:

TABLE 11.—Blue Hill, Mass., United States of America.

Month.	Cl., Cl.-S.	Cl.-Cu.	A.C., A.S.	Lower clouds.	Wind.
January.....	W. 4° N.	W. 4° S.	W. 19° S.	W. 8° N.	W. 10° N.
February.....	W. 1° S.	W. 2° S.	W. 16° S.	W. 9° N.	W. 20° N.
March.....	W. 5° N.	W. 21° N.	W. 27° N.	W. 34° N.	W. 41° N.
April.....	W. 14° N.	W. 38° N.	W. 7° S.	W. 23° N.	W. 39° N.
May.....	W. 22° N.	W. 22° S.	W. 16° S.	W. 1° N.	W. 63° S.
June.....	W. 23° N.	W. 5° N.	W. 14° S.	W. 8° N.	W. 42° S.
July.....	W. 20° N.	W. 3° S.	W. 11° N.	W. 9° N.	W. 36° S.
August.....	W. 4° S.	W. 3° S.	W. 7° N.	W. 5° N.	W. 1° N.
September.....	W. 13° S.	W. 14° S.	W. 15° S.	W. 1° N.	W. 11° N.
October.....	W. 5° S.	W. 5° S.	W. 6° S.	W. 6° N.	W. 18° N.
November.....	W. 2° S.	W. 3° N.	W. 16° S.	W. 7° N.	W. 7° N.
December.....	W. 6° S.	W. 14° S.	W. 7° S.	W. 10° N.	W. 11° N.

(Table 12 omitted: see fig. 4.)

TABLE 13.—Denmark (56° Lat. N.), 1886-1900 (M. H. Nielsen).

Month.	Upper clouds.	Middle clouds.	Lower clouds.	Wind.
January.....	W. 39° N.	W. 40° N.	W. 22° S.	W. 42° S.
February.....	W. 36° N.	W. 39° N.	W. 1° N.	W. 7° S.
March.....	W. 27° N.	W. 32° S.	W. 5° S.	W. 20° S.
April.....	W. 15° S.	W. 75° S.	W. 24° N.	W. 60° N.
May.....	W. 18° S.	W. 44° S.	W. 2° N.	W. 85° N.
June.....	W. 5° S.	W. 16° S.	W. 3° N.	W. 20° N.
July.....	W. 10° N.	W. 5° S.	W. 3° S.	W. 16° S.
August.....	W. 11° S.	W. 37° S.	W. 17° S.	W. 33° S.
September.....	W. 4° N.	W. 17° S.	W. 9° S.	W. 10° S.
October.....	W. 6° S.	W. 10° S.	W. 36° S.	W. 53° S.
November.....	W. 30° N.	W. 20° S.	W. 50° S.	W. 54° S.
December.....	W.	W. 18° S.	W. 42° S.	W. 57° S.

(Table 14 omitted: see fig. 4.)

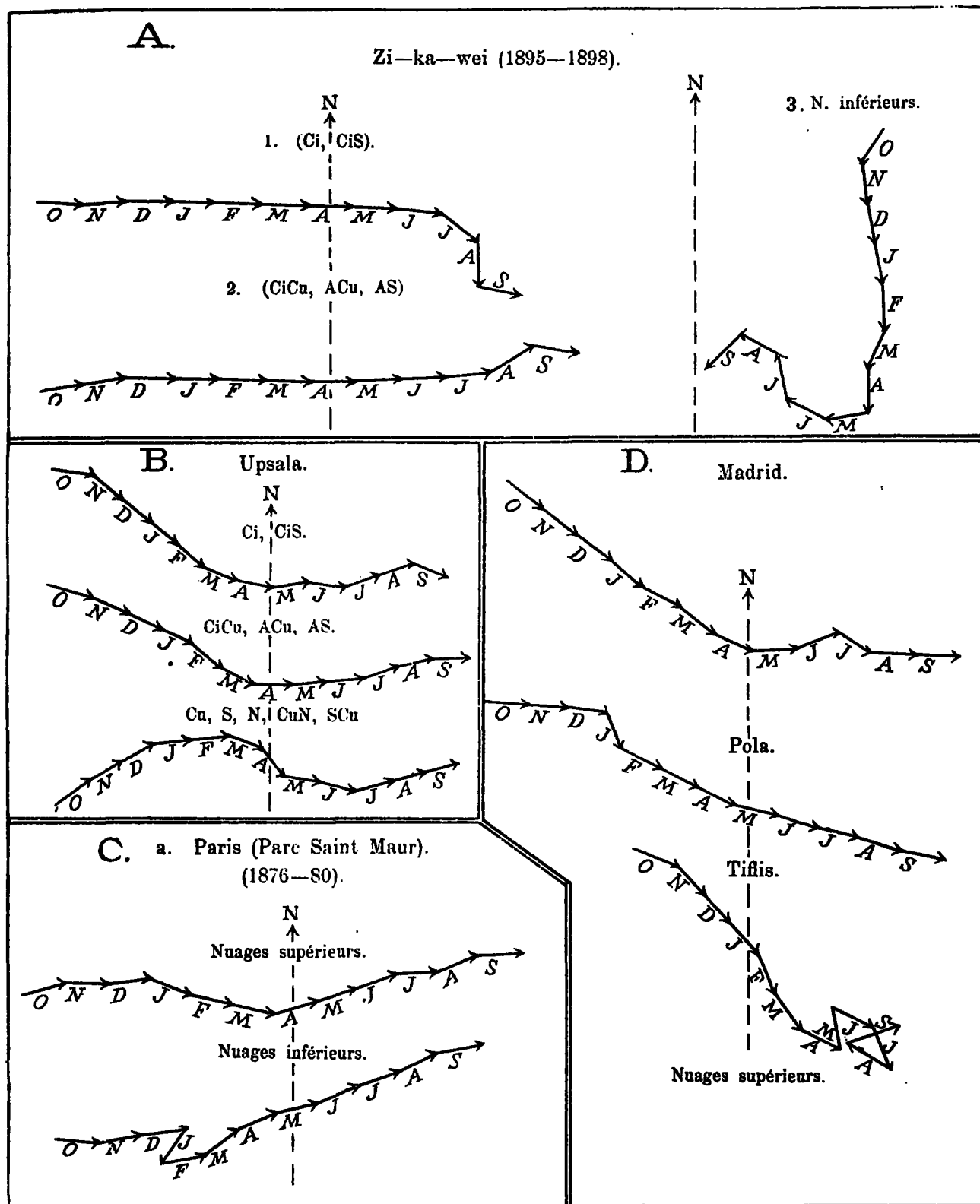


FIG. 4.

TABLE 15.—March of the clouds over Norway, Iceland, and Greenland.

	Latitude.	Longitude.	April-September.			October-March.		
			Upper clouds.	Middle clouds.	Lower clouds.	Upper clouds.	Middle clouds.	Lower clouds.
Lödingen.....	68° 24' N.	16° 1' E.	W. 63° S.	W. 75° S.	W. 54° S.	W. 51° S.	W. 60° S.	W. 49° S.
Drontheim.....	63° 26' N.	10° 22' E.	W. 25° S.	W. 46° S.	W. 23° S.	W. 2° N.	W. 9° S.	W. 2° S.
Aasnes.....	60° 37' N.	11° 58' E.	W. 13° S.	W. 15° S.	W. 80° S.	W. 32° N.	W. 24° S.	E. 53° S.
Christiania.....	59° 55' N.	10° 43' E.	W. 9° S.	W. 9° S.	E. 71° S.	W. 30° N.	W. 29° S.	E. 43° S.
Thorshavn.....	62° 25' N.	6° 45' W.	W. 55° S.	E. 25° S.	W. 25° S.	W. 20° S.	W. 70° S.	W. 28° S.
Reykjavik.....	64° 9' N.	21° 55' W.	E. 70° N.	W. 80° S.	E. 57° S.	E. 50° N.	E. 60° S.	S.
Stykkisholm.....	65° 5' N.	22° 46' W.	W. 3° N.	.....	W. 81° S.	W. 43° N.	.....	W. 76° S.
Telgarhorn.....	64° 40' N.	14° 19' W.	W. 29° N.	.....	W. 3° S.	W. 70° N.	.....	W. 23° S.
Upernivik.....	72° 47' N.	56° 7' W.	W. 86° N.	.....	W. 59° S.	E. 2° S.	.....	E. 46° N.

It is seen that there are some stations, Reykjavik on the southern coast of Iceland especially, where the march of the clouds is from east or northeast. This exception is easily explained. South of Greenland and Iceland there is situated the great mean barometric minimum traversed almost without cessation by the minima moving from west to east. To the north there lie the vast, frigid lands of Iceland and Greenland, always covered with ice, over which there is most often, especially in winter, a high barometric pressure. We have seen (above) that in such a situation the depressions are strongly developed and are closed above (at the north) up to the height of the cirrus clouds. The passage of depressions so marked being almost continual, it follows that at these stations the cirrus clouds are seen moving in general from the east despite the march of the minima from west to east.

At Bossekop (69° 56' N. lat., 23° S' E. long.), a station in Norway, Mohn found cloud measurements in 1896-97 as follows:

TABLE 16.

Height.	Wind direction.
<i>Meters.</i>	
0-1,000.....	W. 23° N.
1,000-3,000.....	W. 12° S.
3,000-5,000.....	W. 12° S.
5,000-7,000.....	W. 12° S.
7,000-10,000.....	W. 9° S.
Above 10,000.....	W. 13° N.

TABLE 17.—Tomsk, Siberia (56° 30' lat. N., 84° 30' long. E.).

Month.	Clouds.			Wind.
	Upper.	Middle.	Lower.	
January.....	W. 42° N.	W. 28° N.	W. 5° S.	W. 32° S.
February.....	W. 50° S.	W. 23° S.	W. 14° S.	W. 85° S.
March.....	W. 34° S.	E. 24° S. (?)	W. 48° S.	E. 52° S.
April.....	W. 13° N.	W. 3° S.	W. 13° S.	W. 59° S.
May.....	W. 73° N.	W. 16° N.	W. 39° N.	W. 3° S.
June.....	W. 37° S.	W. 8° N.	W. 22° S.	W. 49° S.
July.....	W. 20° S.	W. 19° S.	W. 54° S.	E. 24° S.
August.....	W. 22° S.	W. 15° S.	W. 28° S.	W. 66° S.
September.....	W. 4° S.	W. 13° S.	W. 7° S.	W. 52° S.
October.....	W. 2° S.	W. 9° S.	W. 21° S.	W. 59° S.
November.....	E. 79° S.	W. 45° S.	W. 35° S.	W. 72° S.
December.....	W. 19° S.	W. 19° N.	W. 14° S.	W. 62° S.

TABLE 18.—Irkoutsk, Siberia (52° 16' lat. N., 104° 10' long. E.)

Month.	Clouds.			Wind.
	Upper.	Middle.	Lower.	
January.....	W. 43° N.	W. 7° N.	W. 29° N.	W. 5° N.
February.....	W. 45° N.	W. 24° N.	W. 45° N.	E. 36° S.
March.....	W. 45° N.	W. 32° N.	W. 28° N.	E. 78° N.
April.....	W. 16° N.	W. 14° N.	W. 32° N.	E. 33° S.
May.....	W. 40° N.	W. 41° N.	W. 45° N.	W. 23° N.
June.....	W. 11° N.	W. 27° N.	W. 33° N.	E. 80° S.
July.....	W. 27° N.	W. 27° N.	W. 53° N.	W. 65° S.
August.....	W. 13° N.	W. 45° N.	W. 34° N.	W. 24° S.
September.....	W. 22° N.	W. 27° N.	W. 28° N.	W. 14° N.
October.....	W. 27° N.	W. 34° N.	W. 39° N.	W. 34° N.
November.....	W. 45° N.	W. 34° N.	W. 42° N.	W. 41° N.
December.....	W. 45° N.	W. 45° N.	W. 51° N.	W. 69° N.

6. Subtropical zone.

We have seen that the air above the Temperate Zone is drawn in a vast whirl turning from the west, whose center lies in the polar regions; and that in this whirl the air in the lowest strata approaches the center and that of the higher strata departs from it in the same manner as in an ordinary cyclone. Hence we must expect that the upper currents invade the northern slope of the high pressure region of the tropics, which will thus be fed from two sides: by the counter-trade from the southern side and by a current from the northwest from the northern side. This is precisely what takes place.

From observations taken during the "cloud year" the following mean directions at different heights were found at Washington, D. C.

TABLE 19.—Washington (38° 53' lat. N.).

Height.	April-September.	October-March.
<i>Meters.</i>		
0-1,000.....	N. 42° W.	S. 71° W.
1,000-3,000.....	N. 66° W.	N. 87° W.
3,000-5,000.....	N. 34° W.	S. 79° W.
5,000-7,000.....	N. 89° W.	S. 80° W.
7,000-10,000.....	N. 80° W.	N.
Above 10,000.....	N. 77° W.	N. 79° W.

According to observations taken at Fayal, Azores, which were sent to us by M. Chaves, the march of the

cirrus clouds is from the northwest in summer and from west-southwest in winter. In winter Fayal lies in the wind system of the Temperate Zone.

TABLE 20.—*Perpignan, France (42° 41' lat. N.).*

Month.	Upper.	Middle.	Lower.
January.....	W. 31° N.	W. 37° N.	W. 52° N.
February.....	W. 39° N.	W. 33° N.	W. 36° N.
March.....	W. 33° N.	W. 33° N.	W. 24° N.
April.....	W. 31° N.	W. 40° N.	W. 30° N.
May.....	W. 28° N.	W. 28° N.	W. 18° N.
June.....	W. 18° N.	W. 13° N.	W. 10° N.
July.....	W. 17° N.	W. 22° N.	W. 27° N.
August.....	W. 23° N.	W. 14° N.	W. 18° N.
September.....	W. 11° N.	W. 17° N.	W. 12° N.
October.....	W. 15° N.	W. 4° N.	W. 14° N.
November.....	W. 34° N.	W. 29° N.	W. 26° N.
December.....	W. 27° N.	W. 33° N.	W. 32° N.

TABLE 21.—*Cirrus.*

Month.	Madrid (40° 23' lat. N.).	Pola (41° 22' lat. N.).	Tiflis (41° 22' lat. N.).
January.....	W. 46° N.	W. 77° N.	W. 50° N.
February.....	W. 22° N.	W. 25° N.	W. 70° N.
March.....	W. 44° N.	W. 25° N.	W. 56° N.
April.....	W. 20° N.	W. 27° N.	W. 25° N.
May.....	W. 6° S.	W. 12° N.	W. 12° N.
June.....	W. 23° S.	W. 25° N.	W. 28° N.
July.....	W. 32° N.	W. 12° N.	W. 65° N.
August.....	W.	W. 20° N.	W. 20° N.
September.....	W. 1° N.	W. 10° N.	W. 21° S.
October.....	W. 37° N.	W. 8° N.	W. 23° N.
November.....	W. 36° N.	W. 3° N.	W. 50° N.
December.....	W. 35° N.	W. 10° N.	W. 43° N.

According to Dallas the march of the cirrus clouds over the Gulf of Persia is from the northwest at all seasons.

7. Polar regions.

In the polar regions of the northern hemisphere observations of cloud movement are very rare. The Arctic expeditions are generally old, and then such observations were not yet general. During the "polar year," August, 1882–August, 1883, the mean direction of the upper clouds, cirrus and cirro-stratus was as follows:

	October-March.	April-September.
Jan Mayen, 71° N. lat. (Sobieczky).....	W. 23° N.	W. 38° S.
Cape Thorsden, 78° 28' N. lat. (Ekholm).....	W. 55° N.	W. 7° S.

At the most northern station, Treurenberg Bay, on the northern coast of Spitzbergen (79° 59' N. lat.) J. Westman found from July 1899 to August 1900:

Clouds.	October-March.	April-September.
Upper.....	W. 2° N.	W. 75° S.
Middle.....	W. 30° S.	W. 72° S.
Lower.....	W. 6° S.	W. 48° S.

We shall give the results of the Norwegian polar expedition by Nansen, 1893–1896, which moved with the ice from east to west, from the vicinity of Behring Strait as far as Spitzbergen, and the polar expedition by Zeigler to Franz Josef Land. The expedition sojourned at Cape Flora (80° N. lat., 50° E. long.) from May 21 to August 31, 1904, and at Teplitz Bay (81.5° N. lat., 58° E. long.). We have made calculations as if the observations were made at the same station.

Nansen polar expedition of 1893–1896.

Cirrus.....	S. 15° E.	Ci-Cu.....	N. 46° W.
Ci-St.....	N. 66° W.	Nb (lower).....	N. 60° W.
Ci and Ci-St.....	N. 76° W.	Wind.....	S. 23° E.

TABLE 22.—*Franz Josef Land.*

Nuages.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	NE.+ E.+ SE.	SW.+ W.+ NW.
Winter:										
Upper.....			6	1			2	1	7	3
Middle.....	2		10	3	2				15	0
Lower.....	5	16	33	42	27	9	24	4	91	37
Spring:										
Upper.....	3	3	1			1	6	1	4	8
Middle.....	2	6	8	4			4	1	48	5
Lower.....	10	24	36	38	13	14	27	25	98	66
Summer:										
Upper.....	3	10	6	1	3	4	4	5	17	13
Middle.....	2	3	4	6	1	1	6	2	13	9
Lower.....	10	39	50	53	7	9	29	42	142	80
Autumn:										
Upper.....	4	2	6			1	2		8	3
Middle.....	1	3	5	6	2	1	1		14	2
Lower.....	16	29	67	63	29	20	19	9	159	48

Wind: Dec.–Feb., E. to S.; Mar.–Apr., E. to N. (Teplitz); Oct.–Apr., E. to NE., May–July, W. to NW., Aug.–Sept., variable (Cape Flora).

The winds were generally from the east from October to April, from west to northwest from May to July, and very variable in August and September.

Now the wind was from an easterly direction except in Franz Josef Land in summer. The most frequent direction of the clouds there was also that of east to southeast with a secondary maximum from the northwest in summer.

On the North American expedition of the *Fram*, Capt. Otto Sverdrup sojourned on the coasts of Ellesmere Land to the west of Baffin Bay in 1898–1902 (9). The results are summarized in Table I (omitted).

At all elevations winds from the north are generally the most frequent and after these, south winds, which are the prevailing ones in summer.

Only two classes of clouds were considered: Upper (cirrus and cirro-stratus) and lower (including all other forms).

It was feared that the winds were deviated by the north-south direction of the strait which separates Ellesmere Land from Heiberg Land, the stations being situated at the southern entrance of this strait, but according to Capt. Sverdrup the same direction of the wind was observed on the summits of the mountains surrounding the strait and as the winds from north-south have a maximum even at the elevation of the upper clouds this irregularity in the wind system must be accepted—an irregularity which will be explained in what follows.

Observations from the Antarctic Zone are more numerous. In the following tables we give a summary of the observations on the march of clouds and the direction of the wind made by the principal expeditions:

TABLE 23.—*"Scotia," winds.*

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
1. Cape Pembroke (51° 41' lat. S., 57° 42' long. W.).....	19.3	9.9	2.8	2.3	4.9	12.8	22.6	25.1
2. Laurie Island, S. Orkney (60° 43' lat. S., 44° 39' long. W.).....	10.9	2.7	2.1	9.5	9.1	12.5	11.1	38.1
3. Two cruises on Weddel Sea.....	15	17	9	9	7	12	12	13

February and March, 1903, and March, 1904, calms 6 per cent.

The 3 winds from the east were observed only south of latitude 60° S.

TABLE 24.—"Snowhills" march of clouds and winds (64° 22' lat. S. 56° 69' 45" long. W.).

	Cl, ClSt.	ClCu, ASt.	St. Cu, Nb, St.	Wind, per cent.
N.....	0	2	6	0.8
NNW.....	0	3	7	0.2
NW.....	2	4	6	0.3
WNW.....	2	8	6	0.4
W.....	11	16	15	0.4
WSW.....	3	4	7	12.5
SW.....	4	9	13	21.8-54.5
SSW.....	1	6	3	20.4
S.....	1	2	3	4.9
SSE.....	0	1	2	0.7
SE.....	0	2	0	0.9
ESE.....	0	0	1	0.6
E.....	0	0	3	2.1
ENE.....	0	1	1	3.9
NE.....	0	4	3	8.7
NNE.....	0	0	4	4.5
Total.....	24	62	80	(1)

¹ Calm 14.8, variable 2.3.

TABLE 25.—"Gauss" winds, per cent (66° 2' lat. S., 89° 33' E.).

N.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.
0.1	0.2	0.5	3.9	47.8	10.5	4.5	4.8

S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	Calms.
2.0	1.1	1.4	3.4	6.3	1.7	0.9	0.2	10.7

Components in per cent (calms omitted).

	Lat. S.	Long. E.	From E.	From W.
Kerguelen.....	49° 25'	69° 53'	5.4	90.3
Heard Island.....	53° 8'	73° 34'	20.5	73.8
"Gauss".....	66° 2'	89° 33'	73.3	16.0

TABLE 26.—"Belgica," cruise from 69° 38' to 71° 36' lat. S., 80° 30' to 96° 40' long. W.

Winds.	N.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.
Winter.....	249	226	290	131	181	184	142	123
Summer.....	132	147	380	504	502	408	334	228

Winds.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.
Winter.....	198	94	284	254	621	389	323	24
Summer.....	177	132	200	262	215	133	105	84

TABLE 27.—"Southern Cross," Cape Adare 71° lat. S., 170° long. E.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calms.
Winds, per cent.....	3.6	26	9.1	20.4	13.9	4.1	3.1	3.1	40.1
	.....	.....	43.4	.....	.....	.....	.....	.....	.....

TABLE 28.—"Discovery," Ross Island, 77° 50' lat. S., 166° 45' long. E.¹

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
Upper clouds.....per cent..	8	4	6	8	10	26	19	19
Smoke from Mt. Erebus (13,000 feet).....per cent..	4	2	4	8	12	36	28	6
Lower clouds.....do.....	18	10	13	14	18	15	4	8
Winds.....do.....	11	20	44	16	47	6	1	2
	.....	80	.....	.....	.....	.....	.....	.....

¹ National Antarctic Expedition, 1901-1904, Pt. I, p. 495.

8. Barometric maximum of the North Atlantic Ocean.

The movements of the upper layers of air over the barometric maximum of the North Atlantic being of the highest importance for our understanding of the general movements of the atmosphere, we have studied these specially. (10)

For this study we have used, in addition to the results given above, the nephoscopic observations in the Antilles published by Bigelow (11) and those of Chaves from Horta, island of Fayal (Azores). (12) Then we have calculated the means of the observations of upper clouds published by Toynbee in 1876 for squares 38, 39, 40, 2, 3, 4, 301, 302, and 303.

The results are entered on the two charts (figs. 6 and 7) on which the directions of the upper currents seem to appear very much in their general characteristics.

Above the equatorial regions the great upper current from the east is very well indicated. Above Cape Verde it moves from the southeast, afterwards becoming the southwest counter-trade over the southern slopes of the barometric maximum, and finally, deviated more and more to the right, it blows from the west over the crest of the maximum.

In the Antilles, where the trade wind blows from east or east-northeast, the upper currents have a direction entirely opposite. This has been known for a long time from the fact that the ashes of the Antillean volcanoes always fall to the east of the volcanoes.

Bigelow has published the observations in graphs. We reproduce here (fig. 5) one of these plates containing the means of four stations. There is clearly seen the opposition between the lower and the upper currents and also the irregular course of the middle clouds between these the two currents.

North of the barometric maximum, in the subtropical zone the upper winds move generally from northwest or from west-northwest as we have seen above.

Farther to the south, over Ascension Island, the cirrus clouds come from the northeast, which corresponds to their course from southeast at Cape Verde.

The charts show the variations of the upper winds with the seasons, the barometric maximum being most to the north in summer and most to the south in winter.

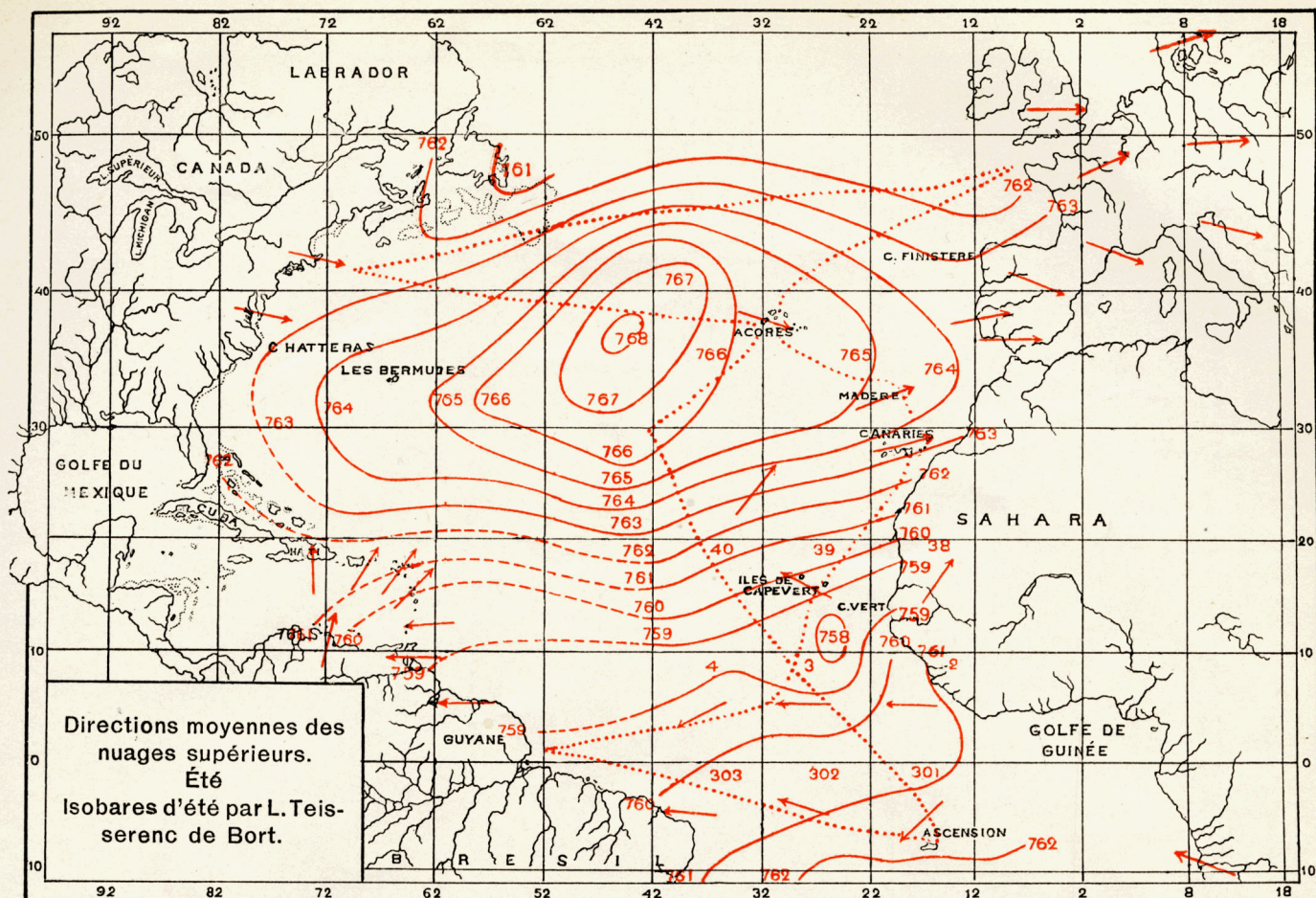


FIG. 6.

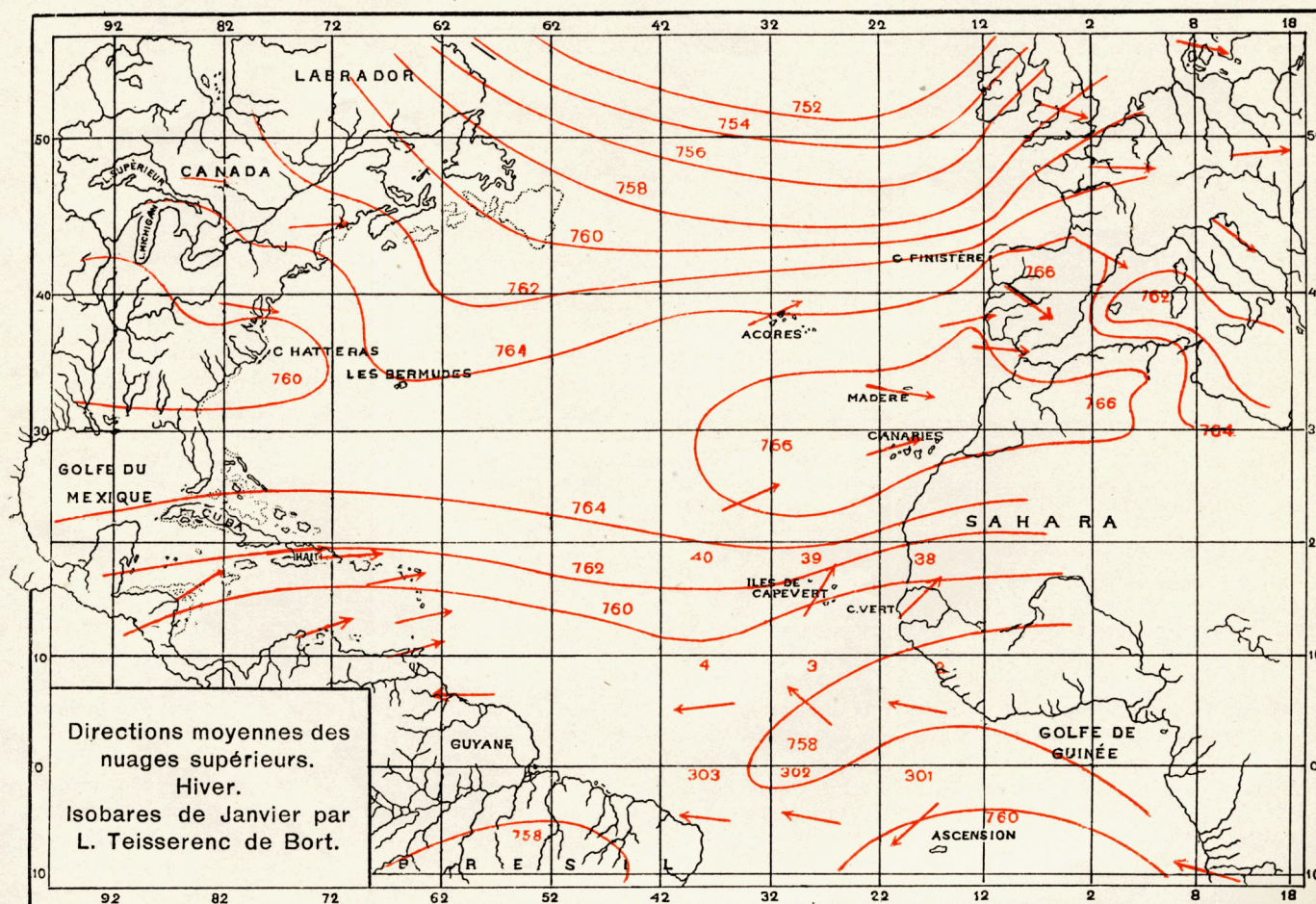


FIG. 7.

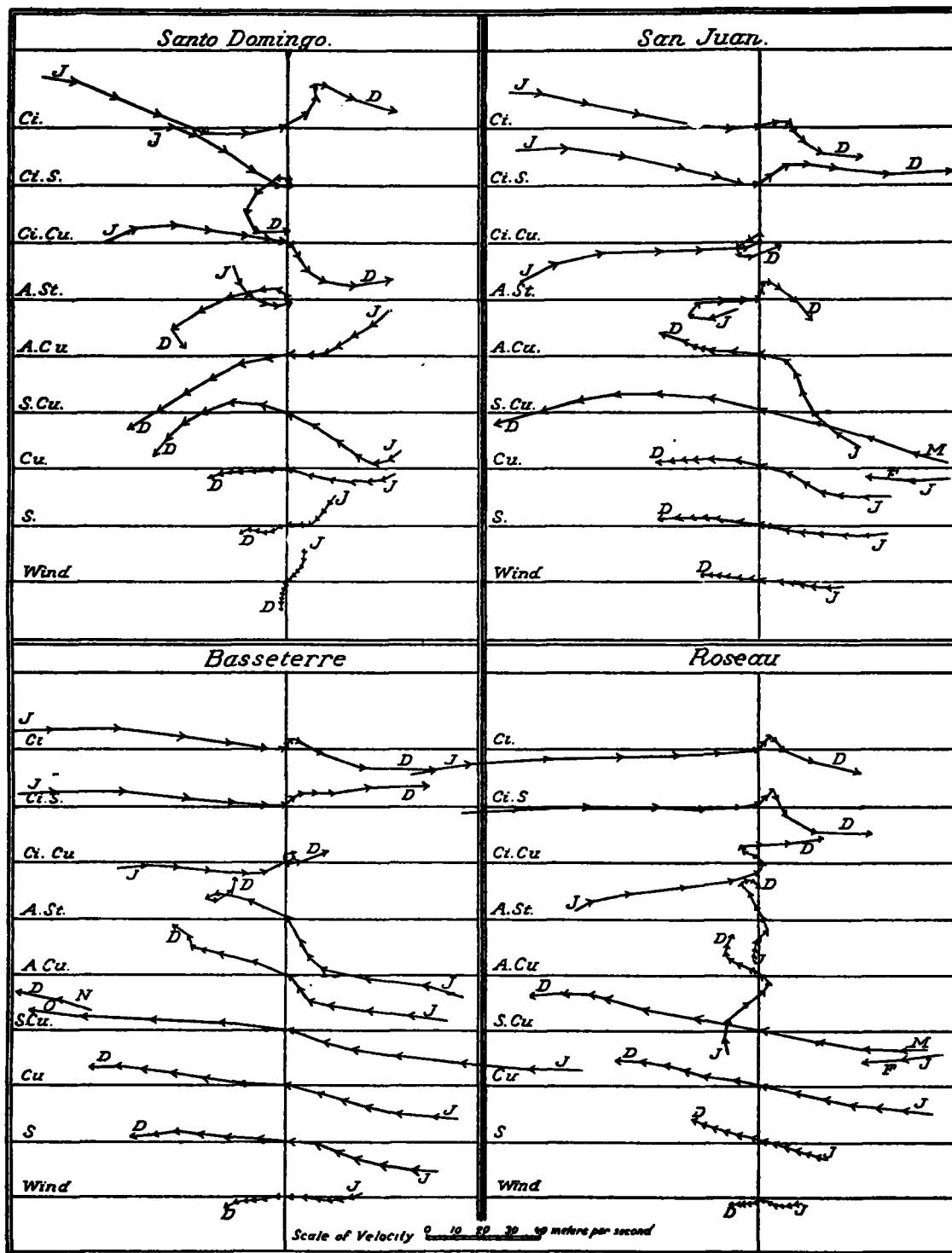


FIG. 5.

III.

AERONAUTICAL OBSERVATIONS.

1. Temperate zone.

It is well known that balloons floating at considerable heights move in general from west to east. The greater the height, the more constantly do the winds move toward the east. This is proven almost every day at all the aerial observatories of Europe and America.

Let us cite merely as an example the flights during the Franco-Swedish expedition at Kiruna, latitude 68° N., in

Swedish Lapland, organized by my lamented friend, Léon Teisserenc de Bort, and myself. (13)

There during March, 1907, February and March, 1908, and August, 1909, 72 balloons were sent up of which 47 were recovered.

Of these balloons there were only 3 which fell on a meridian to the west of Kiruna; one, after having risen to 10 kilometers, fell almost at the same place at which it was set free; but all of the others fell to the east of Kiruna at greater or lesser distances—some as far as Finland, several hundred kilometers from the point of departure. Like upper clouds the direction had in

general a north component in winter and a south component in summer.

In order to study the increasing constancy of the winds from the west with elevation we have calculated separately the number of winds from northwest-southwest and from southeast-northeast at the heights 0-5,000 meters in the observations made at Lindenberg in 1912 by means of pilot balloons. (14)

In the same manner we have calculated the directions of the clouds in the same year at Upsala and those found at the Swedish antarctic station at Snowhill.

And then we have calculated the percentage of winds with east component in all of the winds northwest-southwest and northeast-southeast.

It is seen how the winds with east component decrease considerably with elevation.

LINDENBERG.

	Winds.	1,000 meters.	2,000 meters.	3,000 meters.	4,000 meters.	5,000 meters.
NW-SW.....	65	78	59	42	39	21
SE-NE.....	52	43	35	16	11	8
Total.....	117	121	84	58	41	29
Percent.....	44.4	35.5	29.8	27.6	26.8	27.6
N.....	25	10	8	5	4	2
S.....	22	10	9	7	2	1

UPSALA.

	Winds.	Lower clouds.	Middle clouds.	Upper clouds.
JANUARY-MARCH.				
NNW-SSW.....	531	139	49	33
SSE-NNE.....	422	60	0	0
Total.....	953	199	49	33
Percent.....	44.4	30.2	0	0
N.....	7	2	0	5
S.....	25	1	0	0
JUNE-AUGUST.				
NNW-SSW.....	438	165	62	57
SSE-NNE.....	426	159	29	27
Total.....	864	324	91	84
Percent.....	49.3	49.6	31.9	32.1
N.....	15	1	3	3
S.....	29	10	10	4

SNOWHILL.

YEAR.				
NNW-SSW.....	55.8	57	50	23
SSE-NNE.....	21.1	14	8	0
Total.....	77.2	71	58	23
Percent.....	27.7	19.7	13.8	0
N.....	6	2	2	0
S.....	3	2	2	1

It seems that it should be concluded from this that the cyclones and anticyclones are phenomena which originate in the lower strata of the atmosphere and which do not always reach the upper strata. It is also known that the anticyclones form and remain normally over cold, dry lands, while the minima form most often over the seas.

2. Barometric maximum of the North Atlantic Ocean.

As we have seen, the currents of air above and around the barometric maximum of the Tropic of Cancer are very complicated, but also very interesting to know, if it is desired to study the general movements of the atmosphere. So, hardly had Rotch succeeded in sending kites from a steamer when I proposed to him in 1901 the making of such experiments over this part of the ocean. However, this program was too difficult to be carried out at that time. On one hand the expenses were very considerable and on another the kites did not generally rise to sufficient heights.

But scarcely had Assmann introduced for these experiments small rubber balloons, which ascend with a velocity perceptibly constant, and whose paths can therefore be determined from a single point on the earth or from the bridge of a steamer,¹ when Prince Albert of Monaco, accompanied by Hergesell, undertook two expeditions with his yacht (*Princess Alice*) to carry out such ascensions.

These experiments were carried on in 1904 in the triangle Oporto-Teneriffe-Azores and in 1905 along the route Gibraltar-Sargasso Sea (26° N. lat., 43° W. long.)-Azores (15). These are the results of the first expedition. In the lowest stratum there prevails the northeast trade wind with a mean velocity of 7 m/s. There is an adiabatic decrease in temperature and a relative humidity increasing from 70-80 per cent to 95 per cent, or often 100 per cent. In this case cumulus clouds form at the upper limit, which lies at a height varying between 100 meters and 600 meters. Then the temperature suddenly rises several degrees and the humidity falls to only 20-10 per cent. In this inversion stratum with a thickness of about 1,000 meters the wind is very irregular and light from the northeast,² shifting ordinarily with elevation, from northeast through north toward northwest, but twice (observed) shifting from northeast toward southwest and south. Above the inversion stratum there is found again a stratum with a gradient exactly adiabatic. The relative humidity increases with elevation so that the vapor content (*richesse hygrometrique*) is constant, which permits the inference of a descending current. In this stratum, which extends beyond 4,500 meters, the greatest height reached on this expedition there prevails a wind from the northwest. A counter-trade wind from the southwest was observed but once.

As an example, Hergesell gives the typical results of August 9, 1904 obtained, to the west of the Canary Islands.

TABLE 29.

Height.	Temper- ature.	Relative humidity	Direction of the wind.
<i>Meters.</i>			
0.....	+23.0	80	N. 52° E.
200.....	20.5	88	
400.....	18.5	88	N. 36° E.
500.....	18.0	93	
600.....	18.9	80	
800.....	24.5	35	
1,000.....	26.4	16	N. 20° E.
1,200.....	26.2	16	N. 15° E.
2,000.....	18.0	21	
3,000.....	9.0	30	
4,000.....	1.5?	40	
4,500.....	5.6	47	N. 25° W.

These results were fully verified during the expedition in 1905. Hergesell gives the following summary of observations on the directions of the winds:

August	Lat. N.	Long. W.	Winds in successive strata.
1.....	31° 10'	19° 30'	0-3,420 meters NE., 5,000 NW., 6,740 NE., 7,370 N. and at 10,000 NNW.
2.....	29° 17'	21° 50'	0-3,540 meters NE., 5,450 NW.-WNW., 9,420 NE., 10,200 E., 13,240 ENE.-NNE., above SE.
7.....	25° 58'	35° 7'	0-1,800 meters NE., 2,100 SSE., 5,000 SW., 6,000 SE., 6,600 SSE., 8,400 SW., 9,000 WNW., 12,000 SW., 16,000 SE.
8.....	20° 41'	36° 36'	0-2,110 NE., 12,000 NW.-WNW.
9.....	27° 42'	38° 34'	0-5,600 NE.-NNE., 9,000 NW.-NNW.
11.....	30° 4'	42° 30'	0-4,140 NNE., 4,240 N., 8,400 NNE.
16.....	31° 44'	42° 38'	0-4,540 ENE.
23.....	37° 3'	27° 21'	0-2,210 NE., 2,800 NW., 3,280 NE., 3,840 N., 12,330 NNW.-NW.

¹ We will not treat here the experimental methods employed in these researches—methods well known at present.

² In general, as at Trappes, Hald, etc., the study of HIGGS shows that, in general, there is a zone of light winds at a certain height, a zone through which kites ordinarily can not rise. They form a horizontal line called "la ligne de canards." See also the irregular march of intermediate clouds over the Antilles (Fig. 5) and C. J. P. Cave, The structure of the atmosphere in clear weather, Cambridge, 1912.

The velocity of the trade wind was ordinarily 5 to 6 m/s, that of the upper wind 10 to 15 m/s.

Once, at the most southern station, the upper wind blew from southwest-southeast; everywhere else from northwest. Hence the counter-trade from southwest was found only once.

The expeditions of the *Otaria* fitted out by Teisserenc de Bort and Rotch were more important. The first expedition began July 1, 1905, and the *Otaria* visited in turn Madeira, the Canaries, Cape Verde Islands, the Canaries, and the Azores. The observations consisted, at sea, in flights of kites and pilot balloons; with the exception of those of August 13 the latter were sent from the land in order to have a base which would permit of an exact determination of the path.

The following expedition was made in the month of February, 1906. It was of short duration, its principal purpose being to determine whether the flights made on the open sea gave the same superposition of currents as those made at Teneriffe. The balloons sent up in February demonstrated the existence of the counter-trade wind above the trade in the regions of the Canary Islands. It remained to study the intertropical circulation itself and to pursue soundings in the central portion of the Atlantic.

The third expedition visited in turn Madeira, the Cape Verde Islands, Sierra Leone, Ascension Island, the Cape Verde Islands, Teneriffe, the Azores and then returned to Europe after having sailed a great quadrilateral to the west of the Azores as far as 47° of longitude west of Paris. Leaving Marseilles at the close of April the expedition returned to Havre on October 18.

On this expedition there were made 24 flights of pilot balloons and 46 flights of kites. In calm weather captive balloons carrying self-registering instruments were also often employed, which were in this manner sent to about 5,000 meters, as far as the counter-trade wind.

Then Teisserenc de Bort alone outfitted still another expedition which left Havre on July 1, 1907, for the Azores, where began the first flights of balloons, which were continued chiefly to the southwest of the Cape Verde Islands, which during two periods of 13 to 14 days each permitted the following of the daily circulation at different heights above these parts. Several balloons reached the isothermal stratum in a manner not to be questioned. The ascents were 41 in number, of which 29 were sounding balloons, and of these 20 were recovered giving good curves; the others served as pilot balloons. We give here some typical specimens of the numerous observations. (Tables II-V omitted.)

The general results concerning the circulation of the air are thus summarized by Teisserenc de Bort:

"The wind system is rather regular in a given region and the whole of the circulation over the part explored (35° N. to 8° S. lat., from the coasts of Europe to 47° of longitude west of Paris) can be summarized as follows:

"The regular trade wind from north to northeast, which blows at the level of the sea, forms a stratum whose mean thickness is hardly 1,000 meters, then comes a wind zone still having a north component which blows ordinarily from the northwest. These winds from the northwest appear to cease at 10° from the point of convergence of the trade wind, which in summer is found toward 8° north latitude, consequently to the south of the Cape Verde Islands. Above, at an elevation begins the region of winds with south component which form the counter-trade. The latter are met with at a lesser altitude as the Equator is approached; thus toward the Cape Verde Islands the counter-trade is found

in the neighborhood of 1,800 meters and at the latitude of the Canary Islands it blows above 3,000 meters, which corresponds besides to the observations made on the Peak of Teneriffe.¹

"The equatorial region, that is to say that where lies the point of meeting of the trade winds and whose latitude varies slightly in the course of the year, is occupied by winds with east component very predominant up to the greatest heights that have been explored. From the fifth degree of south latitude there is found above the trade winds proper, winds with north component, which form the counter-trade; these winds are from northeast and sometimes from northwest. These changes in direction can be explained in that these different superposed layers come from different regions of barometric minimum.

"The counterpart of the northwest winds which are met with in the northern hemisphere above the northeast trade wind is given us by the streams of wind from the southwest which are found in the vicinity of Ascension Island above the southeast winds, properly called trade winds of the southern hemisphere. These winds are superposed upon the streams of the trade or counter-trade wind.

"These complications of the strata of different winds are also met with in the northern hemisphere. Examples are found in the paths of balloons determined by sightings made at Trappes during a 10-year period when these flights were made in high pressures.

"In summarizing we can say that the intertropical circulation is indeed in its chief characteristics such as has hitherto been supposed.

"The counter-trade wind in its entirety predominates over great areas, moving from southeast, then from south, from southwest, and finally terminating in a west wind at the latitude of the Azores. Naturally, there are some daily irregularities, and the case is met with where the trade wind extends up to 7 to 8 kilometers and even farther² and where the counter-trade seems to be wanting; but these conditions are of short duration or limited to one portion of the north Atlantic high pressure area, as is seen when the observations are extended over several months of three different years, which permits the determination of the normal system."

Thus the conclusion of Hergesell that the maximum of the North Atlantic is fed from the north by a northwest wind is confirmed. But, thanks to the extension of researches to greater heights, to more southern latitudes, and during several years, all the system of winds developed from cloud observations has been established.

As for the regions of the Antilles, we have seen from the observations of clouds by Bigelow that at the height of the cirro-cumulus or cirro-stratus (7 to 8 kilometers), the counter-trade wind blows from west or west-southwest, exactly opposite to the direction of the trade wind, which blows there from east to east-northeast, and that there is between these currents, at the height of the middle clouds, a stratum with variable winds.

In December, 1909, Hergesell carried on in the region of the Antilles some flights from the *Victoria Louise* of the German Navy. Emperor William paid all of the expenses of the expedition, which embarked on the *Victoria Louise* in the port of St. Thomas, the results of which are given in Table VI.

¹ However, one sees from the tables that this height is very variable.

² Once, July 8, 1906, near Teneriffe a NNE. wind was observed to a height of 11,050 meters.

TABLE VI.

Dec. 6, 1909. 15° 11' N., 66° 58' W. Gr.	Dec. 7, 1909. 15° 41' N., 66° 57' W. Gr.	Dec. 8, 1909. 14° 27' N., 68° 40' W. Gr.	Dec. 9, 1909. 15° 10' N., 67° 31' W. Gr.
<i>Meters.</i> 1,160.....E. 39 N. 2,610.....E. 82 N. 4,060.....E. 5,510.....E. 7 S. 6,960.....W. 78 N. 8,410.....W. 40 N. 8,990.....W. 15 S. 9,570.....W. 20 N. 10,150.....W. 7 S. 11,310.....W. 13 S. 12,760.....W. 27 S. 13,630.....W. 68 S.	<i>Meters.</i> 1,450.....E. 25 N. 2,610.....E. 30 N. 4,920.....E. 13 N. 5,510.....E. 85 N. 6,090.....E. 42 N. 6,670.....E. 7 S. 7,830.....E. 35 N. 8,120.....E. 45 S. 10,730.....W. 7 N. 10,730.....W. 7 N. 11,310.....W. 25 S. 12,470.....W. 29 S. 14,210.....W. 21 S.	<i>Meters.</i> 1,160.....E. 12 N. 2,900.....E. 35 N. 5,510.....E. 7 S. 6,380.....E. 4 N. 8,410.....E. 6 S. 8,700.....Calms. 9,280.....W. 13 S. 10,730.....W. 12,470.....W. 24 S. 13,630.....W. 37 S. 14,790.....W. 21 S. 15,370.....W. 19 N. 16,240.....W. 26 S. 16,530.....E. 47 S.	<i>Meters.</i> 2,570.....E. 33 N. 4,400.....E. 64 S. 4,910.....Calms. 6,740.....E. 8,710.....W. 60 S. 10,920.....W. 28 S. 11,470.....W. 15 N. 12,900.....W. 15,000.....W. 40 S. 16,800.....E. 83 S.
Dec. 10, 1909. 15° 45' N. 67° 21' W. Gr.	Dec. 21, 1909. Noon. 17° 58' N. 75° 58' W. Gr.	Dec. 21, 1909. p. m. 18° 8' N. 75° 30' W. Gr.	Mean curve of the flights Dec. 6-10.
<i>Meters.</i> 2,040.....E. 5 N. 3,760.....E. 25 N. 7,020.....E. 55 S. 8,580.....Variable. 10,470.....W. 30 N. 11,120.....W. 24 N. 13,960.....W. 15 S. 14,570.....Variable. 15,180.....W. 10 S. 15,500.....W. 60 S.	<i>Meters.</i> 1,080.....E. 2,130.....E. 30 N. 2,650.....E. 84 N. 3,400.....W. 30 S. 5,410.....W. 72 S. 6,410.....W. 22 N. 7,190.....W. 4 S. 8,520.....W. 11 N. 9,840.....W. 23 S. 10,010.....W. 20 S. 11,440.....W. 25 S. 11,970.....W. 18 S.	<i>Meters.</i> 1,000.....E. 1,910.....E. 20 N. 3,040.....W. 68 N. 3,720.....W. 40 S. 4,200.....E. 79 S. 5,960.....W. 82 S. 6,730.....W. 12 N. 7,520.....W. 23 N. 8,580.....W. 22 N. 9,900.....W. 16 S. 11,850.....W. 20 S. 12,560.....W. 15 S.	<i>Meters.</i> 1,005.....E. 22 N. 2,955.....E. 31 N. 4,355.....E. 6 N. 5,785.....E. 7,145.....E. 15 N. 8,340.....W. 6 N. 10,285.....W. 3 N. 11,600.....W. 15 S. 13,540.....W. 23 S. 14,100.....W. 45 S.

As is seen, the trade wind blows from the east up to the height of about 7,000 meters. Moreover the velocity of the wind was rather high, 9 m/s, up to 3,000 meters, but light and variable between 3,000 and 7,000 meters. Above began the counter-trade wind from the west, which above 10,000 meters shifted gradually to southwest. Its velocity was on an average 2 m/s.

In order to verify these results Jonas was sent in the following year to make "check" observations with pilot balloons. He arrived with the *Freja* of the German navy at Curaçao (Dec. 1), where he remained until the 9th, then pursued his observation at Port of Spain (Trinidad) from the 11th to 18th, and on the open sea around Trinidad from the 19th to the 23d.

The results [obtained] by Hergesell were fully verified. Up to 4,000 meters the wind from the region of east south-east remained constant and rather strong. From 4,000 to 8,000 meters the winds were light and variable and above that they moved from northwest or southwest.

Hence the results derived from the cloud observations cited above are entirely in agreement with those found by Hergesell and Jonas.

3. Southern Hemisphere.

The officers of several merchant steamers of the Hamburg-South American lines in 1906-1908 sent up pilot balloons along their courses according to instructions from the great institution of the German marine, the Deutsche Seewarte. The results of 65 flights are published by Koppen. (16) These experiments were continued for three years, 1909-1911, by H. Meyer, instructor in navigation of the school of the Norddeutsche Lloyd Co., during long voyages on the Atlantic and on the Pacific. (17) Table VII gives the observations made during 16 flights at a rather great height south of latitude 7° N.

TABLE VII.—The Southern Hemisphere.

1. Apr. 24, 1906. 7° N. 29½° W. Gr.	2. Oct. 31, 1907. 4° 23' N. 29° 52' W.	3. Sept. 25, 1907. 1° 18' N. 30° 51' W.	4. Jan. 6, 1910. 0.2° N. 29.3° W.
<i>Meters.</i> 0.....NE. 500.....N. 57 E. 1,000.....N. 71 E. 1,500.....S. 69 E. 2,000.....S. 60 E. 2,500.....S. 66 E. 3,000.....S. 77 E.	<i>Meters.</i> 0.....SSE. 500.....S. 42 E. 1,000.....S. 36 E. 1,500.....S. 76 E. 2,000.....N. 46 E. 2,500.....N. 65 E.	<i>Meters.</i> 0.....SE. 500.....S. 42 E. 1,000.....S. 64 E. 1,500.....N. 35 E. 2,000.....S. 25 E. 2,500.....S. 38 E. 3,000.....S. 30 E.	<i>Meters.</i> 0.....ESE. 500.....S. 52 E. 1,000.....S. 61 E. 1,500.....S. 70 E. 2,000.....S. 82 E. 2,500.....N. 75 E. 3,000.....N. 70 E. 3,500.....N. 58 E. 4,000.....N. 65 E. 4,500.....S. 70 E. 5,500.....S. 50 E.
5. Mar. 6, 1907. 1° S. 32° W.	6. Jan. 4, 1910. 5.2° S. 30° W.	7. Jan. 5, 1910. 2.1° S. 29.6° W.	8. Jan. 6 1908. 2½° S. 44° 26' W.
<i>Meters.</i> 0.....SSE. 500.....S. 77 E. 1,000.....S. 75 E. 1,500.....S. 76 E. 2,000.....S. 75 E. 2,500.....S. 75 E. 3,000.....S. 75 E.	<i>Meters.</i> 0.....SSE. 500.....S. 62 E. 1,000.....S. 76 E. 1,500.....S. 85 E. 2,000.....E. 2,500.....N. 88 E. 3,000.....N. 75 E. 3,500.....N. 50 E. 4,000.....N. 65 E.	<i>Meters.</i> 0.....E. 500.....N. 73 E. 1,000.....N. 42 E. 1,500.....N. 17 E. 2,000.....N. 47 E. 2,500.....N. 35 E. 3,000.....N. 35 E. 3,500.....N. 35 E. 4,000.....N. 35 E.	<i>Meters.</i> 0.....SSE. 500.....S. 85 E. 1,000.....N. 85 E. 1,500.....S. 15 W. 2,000.....N. 80 W. 2,500.....S. 83 W. 3,000.....N. 70 W. 4,000.....N. 62 W. 5,000.....N. 54 W.
9. Oct. 22, 1910. 15.3° S. 91.1° W.	10. Dec. 1, 1910. 31° S. 161° E.	11. Oct. 30, 1910. 21.4° S. 114.1° W.	12. Nov. 3, 1910. 26° S. 150.4° W.
<i>Meters.</i> 0.....SSE. 500.....S. 85 E. 1,000.....S. 82 E. 1,500.....S. 82 E. 2,000.....E. 2,500.....S. 3,000.....S. 15 W. 3,500.....S. 35 W. 4,000.....N. 85 W. 4,500.....W. 5,000.....S. 75 W. 6,000.....S. 25 W. 7,000.....N. 40 W. 8,000.....N. 40 W. 9,000.....N. 30 W.	<i>Meters.</i> 0.....ESE. 1,000.....N. 25 E. 2,000.....N. 25 E. 3,000.....N. 74 E. 4,000.....N. 84 E. 5,000.....S. 85 E. 6,000.....S. 63 W. 7,000.....S. 37 W. 9,000.....W. 10,000.....N. 88 W. 11,000.....S. 72 W. 12,000.....S. 80 W.	<i>Meters.</i> 0.....ENE. 1,000.....N. 82 E. 2,000.....S. 70 E. 3,000.....S. 28 E. 4,000.....S. 15 E. 5,000.....N. 80 W. 6,000.....N. 75 W. 7,000.....W. 8,000.....N. 85 W.	<i>Meters.</i> 0.....SW. 500.....S. 62 W. 1,000.....S. 82 W. 1,500.....N. 82 W. 2,000.....N. 48 W. 2,500.....N. 65 W. 3,000.....N. 62 W.
13. Nov. 16, 1910. 25.3° S. 158.1° W.	14. Nov. 17, 1910. 25.8° S. 161° W.	15. Nov. 20, 1910. 26.2° S. 170.6° W.	16. Oct. 25, 1910. 17° S. 98.2° W.
<i>Meters.</i> 0.....SE. 1,000.....S. 50 E. 1,500.....N. 42 E. 2,000.....N. 12 E. 3,000.....N. 84 W. 4,000.....N. 84 W. 5,000.....N. 84 W. 6,000.....N. 15 E. 7,000.....E. 8,000.....E.	<i>Meters.</i> 0.....ESE. 1,000.....S. 68 E. 2,000.....S. 3,000.....S. 4,000.....Calms. 5,000.....W. 6,000.....N. 66 W. 7,000.....S. 38 W. 8,000.....S. 8,500.....S. 13 E.	<i>Meters.</i> 0.....E. 1,000.....S. 87 E. 1,500.....N. 72 E. 3,000.....S. 4,000.....S. 45 W. 5,000.....S. 50 W. 5,500.....S. 50 W.	<i>Meters.</i> 0.....ESE. 1,000.....S. 60 E. 2,000.....S. 50 E. 3,000.....S. 36 E. 4,000.....S. 38 E. 5,000.....S. 48 E. 6,000.....S. 26 E. 7,000.....S. 23 E. 8,000.....S. 12 E. 8,500.....S. 20 E.

4. Batavia and Samoa.

Some observations have been made by means of sound- ing or pilot balloons at Batavia, 6° south latitude, and at Samoa, 14° south latitude.

The observations at Batavia from September 16, 1911, to July 5, 1912, are published in the Publications of the Commission on Scientific Aeronautics, 1911-12.

The station is in the northwest monsoon system and that of the southeast trade wind, but, as we have seen, the monsoons are limited to a relatively low layer of the atmosphere. Also it is seen from Table VIII [omitted] that above 100-500 meters there prevail winds from the east, as would be presupposed, Batavia being in the equatorial zone. However, on May 2 a southwest wind prevailed as far as 4,000 meters, where the observations ended. On April 11 there were observed variable winds

between northwest and southwest above 12,000 meters, that is, in the stratosphere. This anomaly presented itself also at 5,000-6,000 meters on June 6. Otherwise, east winds blew at the greatest heights reached.

From 40 years of hourly observations the winds of each month are on an average as follows (18):

January.....	N. 48° W.	July.....	N. 53° E.
February.....	N. 42° W.	August.....	N. 46° E.
March.....	N. 29° W.	September.....	N. 34° E.
April.....	N. 31° E.	October.....	N. 32° E.
May.....	N. 50° E.	November.....	N. 1° W.
June.....	N. 56° E.	December.....	N. 54° W.

Nos. 1 to 6 of Table VII show the easterly current of the tropical zone. No. 7 presents the upper winds from the northeast corresponding to the southeast winds of the Cape Verde Islands. Nos. 8 to 16 contain observations made between South America and Australia in the middle of the trade wind. Under Nos. 8, 9, 11, and 14 are seen the trade wind from southeast and the counter-trade from northwest. No. 15 with upper winds from the southwest corresponds to the upper winds from the northwest in the neighborhood of the Azores. In two cases, Nos. 13 and 14, there are found unusual winds from south to east above 7,000 meters. In No. 10, the polar limit of the trade wind, there are met with above 6,000 meters the west winds of the Temperate Zone as at the northern limit of the trade wind in the north Atlantic. Nos. 12 and 16 show some irregular cases like those we have encountered north of the Equator. No. 12 is an instance in which the southeast trade wind blows from southwest with the regular counter-trade from northwest. We have seen that Teisserenc de Bort once found at the latitude of Teneriffe the northeast trade wind blowing as far as the greatest height reached. No. 16 gives an analogous example for the southeast trade at 17° south latitude on the Pacific Ocean.

From these findings Perlewitz correctly concluded that there is perfect symmetry between the directions of the winds over the North Atlantic and those over the South Atlantic and of the Pacific south of the Equator.

In winter the northwest monsoon is plainly evident, but in summer the southeast trade winds become north-east through local causes, Batavia being situated on the north coast of Java.

We have also some observations from Samoa (14° S. lat.) (19) for the years 1909 and 1910. However, the situation of this island is very exceptional; it could be said that it lies in the Southern Hemisphere in winter and almost in the Northern Hemisphere in summer. In fact the thermal equator, which generally lies north of the Equator removes in summer in this part of the Pacific to the south of 14° south latitude. Then Samoa is situated nearly on the thermal equator, sometimes a little to the north of it, sometimes a little to the south; the winds with east component are, as must be expected, prevalent at all heights. In winter (May-August) the place lies on the contrary most often under the southeast trade winds, and the upper winds have a west component. But the winds at the surface of the earth are often irregular because of land and sea breezes, which are strongly developed.

But the upper currents determined by the course of the cirrus clouds are also irregular. They have most

often a very decided west component. These are observations from that place:

Seasons of the Southern Hemisphere.

	N.	NW.	W.	SW.	S.	SE.	E.	NE.
Summer.....	0	1	4	2	1	2	1	0
Winter.....	0	2	5	1	3	1	0	0

The observations made by the use of kites and pilot balloons rarely extend beyond 3,000 meters. We give here some examples.

Dec. 1, 1910.	Jan. 10, 1910.	Feb. 18, 1910.	Jan. 20, 1909.	May 21, 1909.
<i>Meters.</i> 0-400.....NE. 400-1,200.....N 1,200-2,000.....NNW. 2,000-3,000.....NW. 3,000-3,480.....E. Above—Cist. W.	<i>Meters.</i> 0.....E. 500.....E. 1,000.....E. 1,500.....E. 1,780.....E. Cist.....ESE.	<i>Meters.</i> 0.....E. 500.....ESE. 1,000.....E. 1,125.....E. 1,780.....E. Ci.....SE.	<i>Meters.</i> 0.....NW. 500.....NW. 1,000.....NW. 1,500.....NW. 2,500.....NW. Orange.	<i>Meters.</i> 0.....E. 500.....E. 1,000.....E. 1,170.....E. 2,500.....NW. Cist.....WNW.
May 19, 1910.	June 2, 1909.	July 7, 1910.	Aug. 4, 1910.	Oct. 18, 1910.
<i>Meters.</i> 0-100.....S. 100-200.....Calme. 220-1,870.....ENE. 1,870-2,750.....NW. 2,750-7,100.....NNW. Above—CiCu. W.	<i>Meters.</i> 0.....E. 500.....E. 1,000.....E. 1,500.....E. 1,800.....E. Ci.....WNW.	<i>Meters.</i> 0.....E. 500.....E. 1,000.....E. 1,500.....E. 2,000.....S? Ci.....	<i>Meters.</i> 0-300.....Calme. 300-600.....SSE. 600-2,500.....W.-SW. 2,500-2,900.....Calme. 2,900-5,200.....SSW.-SE. Ci.....SSW.	<i>Meters.</i> 0-200.....ENE. 200-1,200.....E. 1,200-1,400.....ENE. 1,400-2,800.....NE. 2,800-4,100.....NNE.

We see that the wind system of Samoa is not one representative of the air currents of the Tropics. The winds are very changeable from day to day in every month and at every elevation. This depends on the situation of this island between three wind systems—the southeast trade wind, the tropical calm belt, and the monsoons of Australia, New Guinea, and the rather large islands to the west. Because of this the gradients in temperature and pressure of the air are very irregular, wherefore there often arises a wind from the west instead of the east in the upper regions. It [is not our purpose] to discuss here in detail these local anomalies, which do not influence the general movements of the atmosphere.

5. Simultaneous observations in Greenland and Iceland.

We have seen that the course of the cirrus clouds in Greenland and Iceland is on the average from the east instead of from the west as would be expected. Some experiments made by Hergesell with sounding balloons on the sea in these regions have confirmed these observations. In order to study this anomaly more closely, De Quervain of Zurich and Thorkelsen of the Danish Meteorological Institute made simultaneous observations; De Quervain on the west coast of Greenland, between 64° 11' and 68° 51' north latitude, and Thorkelsen at Akureyri on the northern coast of Iceland, from the close of April to the beginning of July in 1909. These most complete observations are found in Table IX (Godthaab 64° 11' N., Agto 67° 56' N., Godhavn 68° 51' N.).

TABLE IX.

Altitude.	Godthaab —Apr. 27.	Akureyri —Apr. 28.	Godthaab —Apr. 29.	Godthaab —May 7.	Akureyri —May 7.	Godthaab —May 12.
<i>Meters.</i>						
0-100.....	N. 30° E.	S. 82° W.	N. 21° W.	E. 30° N.	S. 19° E.	N. 36° E.
500-1,000.....	N. 20° E.	N. 27° W.	N. 24° E.	E. 17° N.	S. 11° E.	N. 42° E.
1,000-1,500.....	N. 20° E.	N. 16° E.	N. 24° E.	S. 30° E.	S. 9° E.	N. 28° E.
2,000-2,500.....	E. 20° N.	N. 33° E.	N. 44° E.	S. 34° E.	S. 51° W.	N. 36° E.
3,000-3,500.....	S. 33° E.	N. 16° E.	N. 29° E.	S. 15° E.	S. 60° W.	E. 7° N.
4,000-4,500.....	E. 25° S.	N. 15° E.	E. 18° S.	S. 4° E.	S. 55° W.	E. 20° E.
5,000-5,500.....	E. 26° S.	.....	E. 18° S.	S. 3° E.	S. 57° W.	S. 30° E.
6,000-6,500.....	E. 28° S.	.....	E. 37° S.	S. 13° W.	S. 44° W.	S. 18° E.
7,000-7,500.....	E. 20° S.	.....	E. 42° S.	S. 9° W.	S. 37° W.	S. 21° E.
8,000-8,500.....	.....	.....	E. 45° S.	S. 5° W.	S. 48° W.	E. 11° S.
9,000-9,500.....	.....	.....	S. 25° E.	.....	S. 45° W.	N. 38° E.
11,000-11,500.....	.....	.....	E. 39° N.	.....	S. 59° W.	E. 30° S.
13,000-13,500.....	.....	.....	E. 41° N.	.....	.....	.....
14,500-15,000.....	.....	.....	E. 10° N.	.....	.....	.....

Altitude.	Akureyri —May 12.	Agto —May 29.	Akureyri —May 29.	Godthaab —June 21.	Akureyri —June 21.	Akureyri —June 22 (soir).
<i>Meters.</i>						
0-100.....	S. 26° E.	S. 25° W.	N. 21° W.	S. 43° W.	S. 54° E.	N. 45° W.
500-1,000.....	S. 29° W.	W. 35° S.	S. 18° W.	E. 17° N.	S. 47° E.	N. 5° S.
1,000-1,500.....	N. 62° W.	W. 41° S.	S. 42° W.	E. 15° S.	N. 64° E.	N. 68° W.
2,000-2,500.....	N. 51° W.	S. 30° W.	S. 30° W.	S. 23° W.	N. 36° E.	N. 45° W.
3,000-3,500.....	N. 38° W.	W. 29° S.	S. 35° W.	W. 31° S.	N. 43° E.	N. 22° W.
4,000-4,500.....	N. 30° W.	W. 2° S.	S. 23° W.	S. 44° W.	N. 40° E.	N. 31° W.
5,000-5,500.....	N. 28° W.	W. 28° N.	S. 17° W.	W. 45° S.	N. 36° E.	N. 10° W.
6,000-6,500.....	N. 30° W.	W. 27° N.	S. 35° W.	S. 37° W.	N. 32° E.	N. 25° W.
7,000-7,500.....	N. 28° W.	.....	.....	S. 38° W.	N. 30° E.	N. 22° W.
8,000-8,500.....	N. 31° W.	.....	.....	W. 39° S.	N. 26° E.	N. 16° W.
9,000-9,500.....	.....	.....	.....	W. 41° S.	N. 29° E.	N. 17° W.

It is seen that at Akureyri winds from the east often prevail in the lower strata, but that there are superposed winds from west to northwest in the upper strata. This is the usual system of winds to the north of a minimum [of pressure] and which is ordinarily open above. The great minima thus pass generally to the south and east of Iceland.

Over the waters of Baffin Bay almost always open and bounded on the east by Greenland always covered with ice and on the west by Ellesmere Land also very frigid there exists almost constantly an almost stationary depression¹ changing more or less in depth. Over Greenland there extends, on the other hand, a tongue of high pressure from the Arctic Ocean. But, as we have seen above, a depression having a high pressure area to the north is closed even above. This explains how the winds are predominantly from the east at all elevations, with few exceptions, in May and June.

We have seen [Table I omitted] that in Ellesmere Land, situated to the northwest of Baffin Bay, the prevailing winds are from the north from the ground as far as into the region of the cirrus clouds. Only in summer are winds from the south prevalent. Hence Ellesmere Land is situated in the rear portion of the constant depression over Baffin Bay. This depression resembles the continuous whirls which form in an inlet cut in the bank of a river. Here the river is the great current from the west prevailing over all of the temperate zone and which we have found in the high regions, even in the polar regions, Jan Mayen, Kiruna, Spitzbergen, Franz Josef Land, etc.

IV.

CONFIRMATION OF THE PRECEDING FINDINGS BY VOLCANIC PHENOMENA.

On the 29th and 30th of March, 1875, a very heavy rain of ashes fell in Scandinavia. The ashes came from the volcano Askja, situated in the eastern part of Ice-

land (65° 2' N. lat., 16° 40' W. long.), whose height is about 1,000 meters. There was a very violent eruption on the morning of March 29. The ashes fell at 7 a. m. on the eastern coast of Iceland between Seidisfjord on the north and Berufjord on the south. At 8 p. m. they fell on the western coast of Norway between Brono on the north and Samnanger near Bergen on the south. Consequently they had crossed the sea with a velocity of 23.8 m/s. At Stockholm the ashes began to fall at 11 a. m. of the following day. On the coast of the Baltic Sea they fell between Sollefteå on the north and Södertelje on the south. Consequently while crossing Sweden the wind had a velocity of 14.1 m/s. On the other coast of the Baltic Sea there were no observations of ashes.

At this time the ashes were carried by the winds of the lower or middle strata of the atmosphere. By the eruption of the volcano Katmai in the Aleutian Islands on June 6-8, 1912, the volcanic products were, on the contrary, thrown into the highest regions of the atmosphere. The finest dust remained there for two to three months after having been carried very rapidly in turn over North America, the Atlantic, and Europe in the form of a fan as far to the east as Siberia. All summer the sky had a grayish color, through this veil the sun appeared like a disk of polished copper. This phenomenon was observed toward the south as far as Bassour in southern Algeria, where it seriously interfered with the work of an actinometric expedition of the astrophysical observatory of the Smithsonian Institute, under the direction of Dr. C. G. Abbot, and A. Ångström, of the University of Upsala. In September, when the phenomenon had almost disappeared in Europe, there were observed, according to a letter from Nakamura, in Japan, red twilights like those observed after the celebrated eruption of Krakatoa.

This eruption of Krakatoa on August 23, 1883, is the most terrible in historic times. The volcano is situated on an island in the strait between Sumatra and Java, near the equator. At 10 a. m. a terrific explosion hurled a great part of the island into the air to a height probably greater than that of the atmosphere. An enormous mass of the finest dust remained suspended in the highest regions, and caused red twilights, which continued for several months. These red twilights made the circle of the earth between the Tropics in 12 days, that is with a velocity of 34.5 m/s. This is the first time that constant equatorial wind from the east around the world was proven.

Along the meridians this phenomenon traveled, on the contrary, very slowly. It arrived at North Cape and at southern Greenland only toward the end of November and at Buenos Aires and Valparaiso at the beginning of October.

These examples, which could be supplemented, prove the existence of a current from west to east in the temperate zone and one from east to west at the Equator.

GENERAL CONCLUSIONS.*

From what precedes there must necessarily be drawn the following conclusions, found without any preconceived theory, and directly from observations made by different methods:

1. About the thermal equator there is a great current from east to west. At the surface of the earth it is generally light (equatorial calms), but very constant and strong in the upper strata of the atmosphere (34 m/s).
2. In the temperate zones there prevail currents from west to east.

¹ Only once, May 5, a depression passed from Baffin Bay to the east over Greenland.

*There is a Review by J. S. Dines in *Nature*, (London) Jan. 2, 1919, pp. 348-349, and *Sci. Am. Suppl.*, Apr. 4, 1919, p. 217.

3. In the upper regions these currents are deviated to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. Thus the equatorial current from the east becomes a current successively from southeast, south, southwest, and west, the counter-trade of the Northern Hemisphere, and successively a current from northeast, north, northwest, and west, the counter-trade of the Southern Hemisphere. These upper currents feed the tropical high pressure regions from the equatorial side. In the same manner the westerly currents of the temperate zones become above northwest and southwest, respectively, and feed the tropical maxima from the polar sides.

4. From these maxima there blow in the lower strata the trade winds from northeast and southeast toward the equator, from directions opposite to the southwest to west winds in the Northern Hemisphere and the northwest to west winds of the Southern Hemisphere.

5. From the polar regions observations are still not very numerous; from those cited above it is seen, however, that winds from the east are frequent at the surface of the earth above latitude 60° to 70° , but that generally winds from northwest to southwest blow above in the upper strata. This is probably explained by the frequent passage of barometric depressions which are not closed above on their polar sides. If, however, there exists a maximum to the north, winds from the east blow above also. Over Baffin Bay, whose waters are more or less open and surrounded by very cold countries, there exists, especially in winter, an almost stationary depression with winds from southeast to east in Greenland and from the north in Ellesmere Land.

6. The greater the elevation, the more constant from the west are the winds of the temperate zones, from which it is to be concluded that cyclones and anticyclones are phenomena that originate in the lower strata of the atmosphere.

7. Hence a direct upper current from the Equator to the poles does not exist, nor a lower current in the opposite direction from the poles to the Equator.

8. However, there is a slow exchange of air along the meridians, caused by continuous cyclonic and anticyclonic whirls in the temperate zones. Indeed each of these whirls carries air on the one side from south to north and on the other from north to south. Besides, as the air has an ascending movement in the cyclones and a descending one in the anticyclones, it is seen that the masses of air from different latitudes become gradually mixed.

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GENERAL CIRCULATION OF THE ATMOSPHERE.

By L. GANGOITI, S. J.

Translation and abstract of 8 folio pages from the report of 1917 of the Meteorological Observatory of Belen College, Habana.

The author discusses the theory of the trades and anti-trades and presents data, principally observations of the direction and movement of high clouds to refute the existence of the anti-trades as set out by Dove and other modern writers.

He refers to observations made at Quito, latitude $0^{\circ} 13'$ south, in June, 1877, of volcanic smoke which rose to an altitude of 8,000 or 9,000 meters and was then carried in a westerly direction by an easterly current. Also he discusses 12 observations of the movement of smoke from Cotopaxi made in Ecuador in the immediate vicinity of the Equator in 1907 and 1908, which show directions as follows: Northwest 1, west or southwest 3, east 4, and southeast 4.

Volcanic ashes from the eruption of Coseguina (Nicaragua) in 1835 fell in Mexico to the northwestward, in Bogota to the southeastward, and in Jamaica to the northeastward, from which he draws the conclusion that there must have been high currents from different directions, i. e., that the southwest anti-trades were not continuous. Observations of smoke from Colima, latitude $19^{\circ} 30' 25''$ N., altitude 3960.9 meters, during 13 months scattered through a period of three years, show that during the period April to September the most frequent quadrant is the northwest; during November, December, and January, the southeast; in February, the southeast and southwest equally; while in March it is the southwest, the latter being the only month that shows a prevalence of the high currents having a direction the same as that attributed to the anti-trades.

Cirrus cloud observations made in Ecuador during 38 months in 1907, 1908, 1909, and 1910 show that by far the most frequent direction is the northeast (29 months), and next the northwest (7 months), while in two other months the number of observations of northeast and northwest currents was equal.

Cloud observations at Port of Spain, Trinidad, latitude $10^{\circ} 35'$ N., show that the cirrus move from the west from